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# Two Standard Precipitation Gages and the Gamma Transmission Snow Gage: a statistical comparison

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Data from two types of recording precipitation gages and a gamma transmission profiling snow gage installed near Soda Springs, in the Sierra Nevada of California, were statistically compared. Precipitation catches by a weighing bucket and a tipping bucket gage were closely correlated ($r = 0.9832$), but weighing bucket gage catch and snow gage measurement were less closely correlated ($r = 0.9246$). Equations have been developed for predicting weighing bucket gage catch from tipping bucket catch. Also presented are equations for predicting weighing bucket catch from changes in snowpack water equivalent that have occurred from one snow gage measurement to the next.

*Retrieval Terms:* precipitation gage catch, comparison, weighing bucket, tipping bucket, gamma transmission profiling snow gage, snowfall

Several types of precipitation gages with different measuring mechanisms are being used at weather stations throughout the United States. Is the statistical relationship adequate for one gage to be used in place of another? Harsh weather conditions, especially snowfall, make precipitation difficult to measure. Is one type of gage more suitable for measuring snowfall than another? The effects of wind on gage catch have been studied extensively.[1] Catch variations between weighing bucket and heated tipping bucket precipitation gages of equal orifice have been statistically compared in only two studies, these being in geographic areas where storm totals were small (5-20 mm water equivalent).[2] No studies that compare these precipitation gages in areas influenced by the maritime climate patterns have been found. Storms in these areas normally occur as large events with 5-20 cm of water in the form of moderately wet snow.

This note reports a statistical comparison of the measurements from two types of recording precipitation gages and a gamma transmission profiling snow gage. Weighing bucket and tipping bucket gages with an 8-inch (20 cm) orifice—which measure both rainfall and snowfall—were compared to determine linear regression coefficients, which can be used to adjust catch amounts between the two gages. The tower-mounted weighing bucket gage and the gamma transmission snow gage—which measures the snowpack to obtain its depth, average density, and thus water equivalent—were compared to illustrate the differences between precipitation measured by each.

Results indicate a close statistical relationship between catches of the weighing and tipping bucket precipitation gages and between the weighing bucket gage and the profiling snow gage. The results verify, however, that both the weighing bucket and tipping bucket gages undermeasure precipitation during snowfall.[2,3] During periods of no melt, the gamma transmission snow gage acceptably estimates ground truth precipitation.

## STUDY SITE

The two precipitation gages and the gamma transmission snow gage are at the Forest Service's Central Sierra Snow Laboratory near Soda Springs, California, at 6885 ft (2099 m) elevation in the Sierra Nevada. The test area slopes gently toward the south, is subject to major high altitude storms, and is influenced by maritime climate patterns. Large storms of moderately wet snow (5-20 cm water equivalent per storm) often occur. The snowpack reaches an average depth of about 12 ft (4 m) and has minimal surface roughness with little or no drifting.

The gages are in a circular forest opening about 200 ft (62 m) in diameter (*fig. 1*). The weighing bucket and tipping bucket precipitation gages are on top of 35 ft (11 m) and 25 ft (8 m) towers, respectively. The two towers are 25 ft (8 m) apart and do not obstruct each other in relation to the storm path. The gamma transmission profiling snow gage is 6 ft (2 m) east of the weighing bucket tower. Measurements obtained with a hand level, from the top of the two towers, indicated no obstacles within the standard 45° from the horizontal plane (*fig. 1*).[4] These measurements indicate that the site is within the general guidelines for the measurement of precipitation in a forest opening.

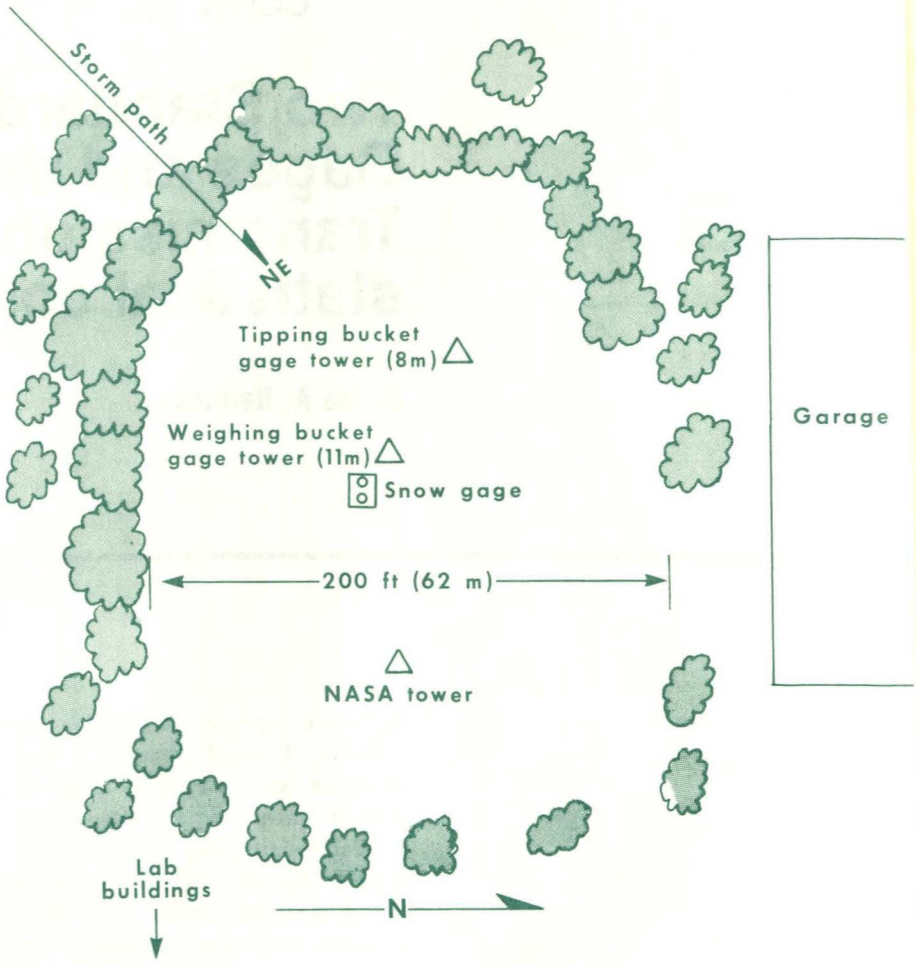


**Figure 1**—Study area and precipitation gages were at the Central Sierra Snow Laboratory near Soda Springs, California, at 6885 ft (2099 m) elevation in the Sierra Nevada.

## INSTRUMENTATION

### Weighing Bucket Precipitation Gage

The weighing bucket gage is a Belfort weighing recording precipitation gage with an 8 inch (20 cm) diameter orifice above a 2½ gal (9.5 liter) bucket.[5] The gage has a capacity of 12 inches (30.5 cm) of precipitation and is a dual traverse mechanism (6 inches [15.25 cm] up and 6 inches down). The gage orifice is surrounded by a standard Alter shield which inhibits wind flow across the orifice to create a calm area that allows snow to enter the gage. The interior is kept dry by a 50 watt d.c. light bulb. A 3 inch (7.5 cm) precipitation equivalent antifreeze and oil mix is used to initially "charge" the bucket so snow will melt as it falls into the solution. Evaporation from the bucket is minimal due to the oil skim which stays on the surface of the antifreeze, oil, and precipitation mix. The gage, calibrated according to the manufacturer's instructions, is of proven reliability.

### Tipping Bucket Precipitation Gage

The tipping bucket gage is a Weather Measure heated recording tipping bucket precipitation gage with an 8 inch (20 cm) diameter orifice that is funnel shaped down to a ¼-inch (0.65 cm) opening. Precipitation is measured by a dual compartment bucket. When 0.01 inch (0.25 mm) of water accumulates in one of the compartments, it tips and the other compartment is brought into position to catch precipitation. The gage orifice and tipping mechanism are heated by a propane flame to about 42° F (5.5° C) so snow will melt as it enters the orifice. The gage is surrounded by a standard Alter shield for wind control. Evaporation during storms is minimal and, because the gage does not store precipitation, is negligible after storms. The gage, calibrated according to the manufacturer's instructions, is of proven reliability.

### Gamma Transmission Profiling Snow Gage

The gamma transmission profiling snow gage consists of two upright tubes, set in concrete, 26 ¼ inches (66.7 cm) apart,[6] each of which contains a probe. One probe is a Cesium 137 radioactive source and the other, an energy-sensitive detector; both probes are at the same horizontal level in the tubes. A low power d.c. motor raises and lowers the probes at a constant speed of 1 ft/min (0.01 m/s). The detector senses energy produced when the gamma particles collide with a ½ inch (1.3 cm) diameter sodium iodide

crystal, and the resulting "count rate" is reduced by a series of electronic instruments to obtain snow density. A density profile of the snowpack is obtained and total snowpack water equivalent is determined. The accuracy of the gamma transmission snow gage in relation to actual physical measurements with newly fallen snow with a density less than 0.10 g/cm$^3$, ice, and polyethylene blocks is 98 percent of true.[6]

### Anemometer and Wind Vane

An anemometer and wind vane are positioned above the weighing bucket precipitation gage. The anemometer measures the run of the wind in 1- and 1/60-mile (1.6 and 0.03 km) increments. The wind vane indicates eight wind directions (E, SE, S, SW, W, NW, N, NE). The windspeed and direction are recorded on an Esterline Angus chart recorder.

## PROCEDURE

Daily precipitation amounts were obtained from both the weighing bucket and the tipping bucket precipitation gages. If a gage was not operating for any part of a 24-hour period, data for that period were excluded from the data base. Differences in condensation accumulation and evaporative loss from weighing bucket precipitation storage and the tipping bucket funnel were considered insignificant and were excluded from this comparison.

For periods when no obvious or suspected melt occurred, changes in total snowpack water equivalent, obtained from snow gage measurements, were compared with the weighing bucket gage catch. Temperature trends throughout previous periods of clear weather and the average density of the snowpack were used to determine whether the snowpack had reached its maximum water holding capacity. West found that evaporation from the snow surface in a natural forest opening was 1 to 2 percent of total water equivalent, and condensation on the snow surface replaced almost half the water lost to evaporation.[7] Because of the small amounts involved, evaporation and condensation were not considered in this analysis. Also, rain-on-snow events were not included in the data base.

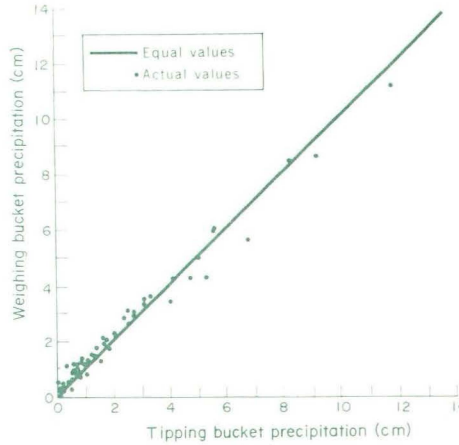


**Figure 2**—Precipitation catches from the tipping and weighing bucket gages were closely correlated.

Windspeed and direction were averaged over each 24-hour period to find their effect on the difference in catch totals between the two precipitation gages. Other wind effects were considered to be the same for both precipitation gages because of their proximity, identical wind shielding, and the variability of the wind during the 24-hour period (*fig. 1*). Upwind and downwind clearing edge effects on differential gage catch were also not considered.

A linear correlation coefficient and standard error were computed from values recorded by the two precipitation gages. A simple linear regression analysis of 236 observations was used to predict weighing bucket precipitation gage catch from tipping bucket precipitation gage data. The same technique was used to estimate weighing bucket precipitation gage catch from a change in snow gage water equivalent.

## RESULTS AND DISCUSSION

All data were for snowfall, except data from June, July, August, and September each year, which were for small amounts of rainfall.

### Weighing and Tipping Bucket Gages

Tipping bucket and weighing bucket precipitation gages were comparable in terms of precipitation recorded during a particular storm (*table 1, fig. 2*). The correlation coefficient was 0.9832. I predicted weighing bucket precipitation gage catch from tipping bucket gage data using $P_w = a_0 + a_1P_t$, in which $a_0$ (0.21042) and $a_1$ (0.97886) are regression coefficients (*table 1, fig. 3*), and $P_w$ and $P_t$ are weighing bucket and tipping bucket precipitation, respectively.[8]

On the average, the tipping bucket gage recorded 88 percent of precipitation recorded by the weighing bucket. At times, the weighing bucket gage recorded up to 0.10 inch (0.25 cm) of precipitation while the tipping bucket gage recorded none. This difference can be attributed to several factors. At the beginning of most storms, during cold conditions with snowfall of low density, intensity, and velocity, the propane flame caused convective heat turbulence, which kept some snow from entering the orifice until intensities and flake velocities were high enough to overcome the updrafts. This convective turbulence was verified by visual observation. The

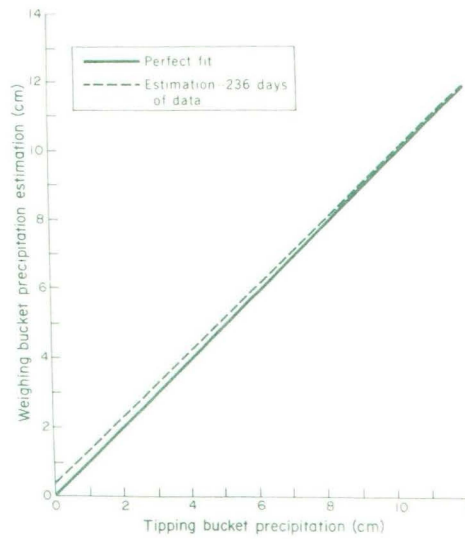


**Figure 3**—Catch by the weighing bucket precipitation gage was estimated by linear regression analysis of catch by the tipping bucket precipitation gage.

Table 1—*Weighing and tipping bucket precipitation gage catches over 24-hour periods*

| Date | Tipping bucket | Weighing bucket |
|---|---|---|
| | *cm* | |
| 1977 | | |
| Sept. | | |
| 28 | 0.99 | 0.84 |
| 29 | 0.56 | 0.69 |
| Oct. | | |
| 27 | 1.48 | 1.27 |
| 28 | 0.00 | 0.05 |
| 29 | 0.15 | 0.43 |
| 30 | 0.03 | 0.08 |
| Nov. | | |
| 4 | 0.61 | 0.97 |
| 5 | 2.01 | 2.01 |
| 20 | 0.53 | 1.17 |
| 21 | 11.51 | 10.85 |
| 22 | 0.43 | 0.25 |
| 24 | 0.00 | 0.20 |
| Dec. | | |
| 4 | 0.00 | 0.05 |
| 11 | 1.73 | 1.70 |
| 13 | 0.43 | 0.58 |
| 14 | 5.36 | 5.77 |
| 15 | 3.91 | 3.33 |
| 16 | 1.17 | 1.50 |
| 17 | 6.60 | 5.46 |
| 18 | 1.02 | 1.17 |
| 19 | 0.00 | 0.05 |
| 20 | 0.00 | 0.51 |
| 21 | 1.57 | 1.88 |
| 22 | 5.11 | 4.19 |
| 23 | 2.44 | 2.54 |
| 24 | 0.00 | 0.38 |
| 26 | 1.96 | 2.21 |
| 27 | 1.23 | 1.47 |
| 28 | 2.41 | 3.02 |
| 29 | 3.00 | 3.23 |
| 30 | 0.74 | 0.71 |
| 31 | 0.00 | 0.25 |
| 1978 | | |
| Jan. | | |
| 1 | 0.08 | 0.30 |
| 2 | 0.89 | 1.14 |
| 3 | 0.79 | 1.32 |
| 4 | 2.97 | 3.40 |
| 5 | 8.05 | 8.23 |
| 6 | 0.53 | 0.89 |
| 8 | 0.66 | 1.14 |
| 9 | 4.57 | 4.17 |
| 10 | 0.25 | 1.09 |
| 11 | 0.15 | 0.30 |
| 12 | 0.18 | 0.25 |
| 16 | 8.97 | 8.41 |
| 17 | 1.55 | 2.06 |
| 18 | 1.02 | 1.19 |
| 19 | 0.64 | 0.74 |
| Feb. | | |
| 1 | 0.86 | 0.96 |
| 2 | 0.18 | 0.43 |
| 5 | 3.20 | 3.38 |
| 6 | 4.09 | 4.17 |
| 7 | 4.88 | 4.83 |
| 8 | 2.64 | 2.72 |
| 9 | 1.98 | 2.16 |

| Date | Tipping bucket | Weighing bucket |
|---|---|---|
| | *cm* | |
| 1978 | | |
| Feb. | | |
| 12 | 2.24 | 2.26 |
| 13 | 0.48 | 0.81 |
| 14 | 0.08 | 0.13 |
| 15 | 0.36 | 0.51 |
| 27 | 0.05 | 0.13 |
| Mar. | | |
| 1 | 1.32 | 1.73 |
| 2 | 2.64 | 2.78 |
| 3 | 1.63 | 2.03 |
| 4 | 5.41 | 5.82 |
| 5 | 2.26 | 2.77 |
| 6 | 0.00 | 0.20 |
| 8 | 0.03 | 0.18 |
| 9 | 0.00 | 0.05 |
| 10 | 0.13 | 0.25 |
| 11 | 0.79 | 1.22 |
| 12 | 0.00 | 0.05 |
| 21 | 0.91 | 1.27 |
| 22 | 0.05 | 0.56 |
| 23 | 1.07 | 1.22 |
| 29 | 0.03 | 0.05 |
| 30 | 0.25 | 0.38 |
| 31 | 1.65 | 2.21 |
| Apr. | | |
| 1 | 0.76 | 1.27 |
| 4 | 0.91 | 1.17 |
| 5 | 0.05 | 0.05 |
| 6 | 3.38 | 3.63 |
| 14 | 0.43 | 0.56 |
| 15 | 2.62 | 2.79 |
| 16 | 1.85 | 1.83 |
| 19 | 1.40 | 1.37 |
| 20 | 3.00 | 2.97 |
| 28 | 0.23 | 0.36 |
| 30 | 0.61 | 0.74 |
| May | | |
| 14 | 0.08 | 0.18 |
| 15 | 2.13 | 2.27 |
| June | | |
| 27 | 0.96 | 1.11 |
| July | | |
| 6 | 0.46 | 0.51 |
| Aug. | | |
| 8 | 0.03 | 0.00 |
| Sept. | | |
| 4 | 0.61 | 0.74 |
| 5 | 4.24 | 4.42 |
| 6 | 0.41 | 0.51 |
| 7 | 0.36 | 0.38 |
| 8 | 0.03 | 0.00 |
| 9 | 2.26 | 2.24 |
| 10 | 1.22 | 1.02 |
| 13 | 0.20 | 0.23 |
| 14 | 0.05 | 0.10 |
| Nov. | | |
| 2 | 0.05 | 0.08 |
| 20 | 1.47 | 1.52 |
| 21 | 1.42 | 0.96 |
| 30 | 0.51 | 0.53 |

| Date | Tipping bucket | Weighing bucket |
|---|---|---|
| | *cm* | |
| 1978 | | |
| Dec. | | |
| 1 | 1.47 | 1.85 |
| 4 | 0.41 | 0.61 |
| 5 | 0.25 | 0.18 |
| 16 | 0.05 | 0.18 |
| 17 | 4.95 | 5.23 |
| 18 | 0.86 | 0.79 |
| 1979 | | |
| Jan. | | |
| 3 | 0.38 | 0.41 |
| 4 | 0.10 | 0.33 |
| 5 | 0.03 | 0.18 |
| 7 | 0.33 | 0.79 |
| 8 | 1.85 | 2.28 |
| 10 | 2.59 | 2.67 |
| 11 | 6.47 | 7.34 |
| 12 | 1.75 | 1.83 |
| 13 | 0.03 | 0.08 |
| 24 | 0.23 | 0.38 |
| 28 | 0.05 | 0.05 |
| 30 | 0.23 | 0.51 |
| 31 | 0.48 | 0.61 |
| Feb. | | |
| 1 | 0.61 | 0.94 |
| 2 | 0.05 | 0.23 |
| 13 | 5.77 | 5.99 |
| 14 | 2.18 | 2.64 |
| 15 | 0.25 | 0.46 |
| 16 | 1.68 | 2.08 |
| 19 | 0.33 | 0.43 |
| 20 | 2.57 | 3.25 |
| 21 | 2.46 | 3.23 |
| 22 | 3.07 | 3.81 |
| 23 | 0.79 | 1.02 |
| 26 | 0.86 | 1.22 |
| Mar. | | |
| 1 | 1.02 | 1.14 |
| 3 | 0.38 | 0.58 |
| 11 | 0.05 | 0.08 |
| 15 | 2.01 | 2.51 |
| 16 | 0.36 | 0.69 |
| 17 | 0.30 | 0.41 |
| 18 | 0.03 | 0.30 |
| 22 | 0.13 | 0.13 |
| 26 | 1.52 | 1.73 |
| 27 | 4.29 | 4.87 |
| 28 | 0.25 | 0.89 |
| Apr. | | |
| 5 | 0.23 | 0.28 |
| 6 | 0.94 | 1.35 |
| 9 | 0.28 | 0.61 |
| 10 | 0.36 | 0.48 |
| 11 | 0.41 | 0.91 |
| 18 | 0.56 | 0.51 |
| 26 | 2.97 | 3.05 |
| 27 | 0.05 | 0.05 |
| May | | |
| 1 | 0.15 | 0.13 |
| July | | |
| 20 | 0.89 | 0.58 |
| 21 | 0.94 | 1.19 |

Table 1—*Weighing and tipping bucket precipitation gage catches over 24-hour periods* (continued)

| Date | Tipping bucket | Weighing bucket |
|---|---|---|
| | *cm* | |
| 1979 | | |
| Aug. | | |
| 7 | 0.08 | 0.08 |
| 28 | 0.97 | 0.94 |
| 29 | 0.28 | 0.25 |
| 30 | 0.74 | 0.97 |
| Oct. | | |
| 8 | 0.23 | 0.20 |
| 13 | 0.71 | 0.61 |
| 14 | 0.03 | 0.08 |
| 15 | 1.42 | 1.37 |
| 16 | 0.05 | 0.05 |
| 28 | 0.10 | 0.20 |
| 30 | 0.13 | 0.25 |
| Nov. | | |
| 2 | 0.13 | 0.18 |
| 3 | 0.98 | 2.44 |
| 4 | 0.28 | 0.76 |
| 9 | 0.03 | 0.00 |
| 22 | 1.14 | 1.42 |
| 23 | 0.46 | 0.91 |
| 24 | 0.32 | 1.91 |
| 25 | 0.45 | 1.85 |
| 26 | 0.38 | 0.36 |
| Dec. | | |
| 19 | 0.25 | 0.51 |
| 20 | 0.89 | 1.35 |
| 21 | 2.11 | 2.57 |
| 1980 | | |
| Jan. | | |
| 7 | 0.43 | 0.51 |
| 8 | 0.33 | 0.10 |
| 9 | 5.05 | 5.08 |
| 15 | 1.19 | 1.30 |
| 16 | 4.57 | 4.39 |
| 17 | 0.89 | 1.50 |
| Feb. | | |
| 3 | 0.25 | 0.23 |
| 14 | 3.05 | 2.95 |
| 20 | 2.77 | 2.51 |
| 22 | 1.47 | 1.96 |
| 27 | 0.94 | 1.07 |
| 28 | 1.40 | 1.52 |
| Mar. | | |
| 1 | 0.18 | 0.58 |
| 5 | 4.17 | 4.72 |
| 6 | 1.17 | 1.96 |
| 11 | 0.56 | 0.99 |
| 12 | 0.10 | 0.05 |
| 17 | 0.30 | 0.51 |
| 18 | 0.76 | 1.70 |
| 20 | 1.42 | 2.13 |
| Apr. | | |
| 1 | 1.45 | 1.45 |
| 4 | 0.58 | 0.58 |
| 5 | 3.99 | 4.70 |
| 6 | 1.07 | 1.65 |
| May | | |
| 23 | 0.41 | 0.69 |
| 25 | 0.18 | 0.30 |
| June | | |
| 30 | 0.71 | 0.64 |
| July | | |
| 1 | 0.36 | 0.30 |
| 2 | 3.25 | 3.25 |
| 28 | 0.10 | 0.15 |
| Sept. | | |
| 9 | 0.08 | 0.08 |
| 10 | 0.05 | 0.05 |
| Oct. | | |
| 11 | 0.23 | 0.48 |
| 12 | 2.01 | 1.65 |
| 25 | 1.73 | 1.91 |
| Nov. | | |
| 7 | 2.16 | 2.79 |
| 22 | 0.15 | 0.28 |
| 23 | 0.43 | 0.84 |
| 30 | 2.16 | 2.44 |
| Dec. | | |
| 21 | 1.22 | 1.27 |
| 24 | 0.03 | 0.05 |
| 25 | 0.05 | 0.00 |
| 1981 | | |
| Jan. | | |
| 3 | 0.25 | 0.18 |
| 4 | 1.09 | 1.07 |
| 5 | 0.08 | 0.05 |
| 16 | 0.53 | 0.64 |
| 17 | 0.18 | 0.33 |
| 19 | 0.25 | 0.53 |
| 21 | 0.03 | 0.05 |
| 24 | 0.30 | 0.64 |
| 26 | 0.43 | 1.19 |
| 27 | 9.42 | 9.98 |
| 28 | 4.17 | 4.85 |
| 29 | 1.30 | 0.52 |
| Feb. | | |
| 8 | 0.08 | 0.46 |
| Sum | 304.14 | 347.37 |
| Mean | 1.2887 | 1.4719 |
| Standard error | | 0.3188 |
| r square | | 0.9666 |
| Regression coefficients | | |
| $a_0$ | | 0.21042 |
| $a_1$ | | 0.97886 |

10 ft (3 m) height disparity between the two towers may have had an effect on gage catch due to possible vertical wind profile differential between the two towers. Also, different gage locations could account for some of the catch variation. Although the correlation coefficient of 0.9832 indicates a high degree of linearity, storm-by-storm variation can be quite large. Also, the probability of two identical precipitation gages consistently recording the same amount is low.

## Weighing Bucket Versus Profiling Snow Gage

For a particular storm, weighing bucket precipitation gage catch and change in snowpack water equivalent from the gamma transmission profiling snow gage were closely correlated; the correlation coefficient was 0.9246. Although this coefficient indicates linearity, it is lower than that obtained by comparing weighing bucket and tipping bucket precipitation gage data. On the average, the weighing bucket precipitation gage recorded 88 percent of snowpack change in water equivalent. This comparison verifies the hypothesis that precipitation gages undermeasure precipitation during snowfall (*table 2, fig.4*).[2 3] I predicted weighing bucket

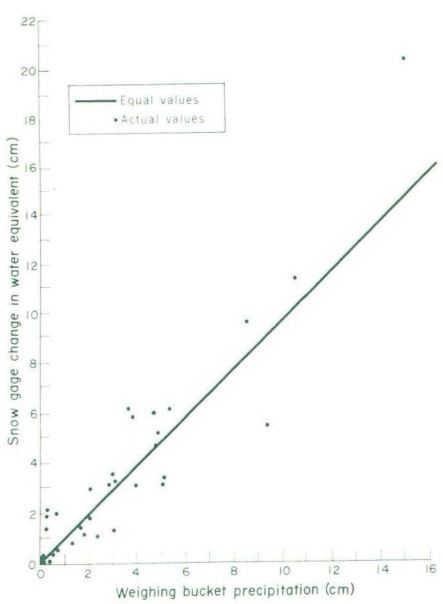


**Figure 4**—Precipitation catch by the weighing bucket gage was not as closely correlated to the change in snowpack water equivalent by the snow gage as it was to precipitation catch by the tipping bucket gage.

Table 2—*Weighing bucket precipitation and snow gage change in water equivalent, from one snow gage measurement to the next*

| Date | Weighing bucket precipitation | Snow gage change in water equivalent |
|---|---|---|
| | *cm* | |
| 1977 | | |
| Dec. | | |
| 12 | 1.70 | 1.14 |
| 16 | 9.04 | 5.38 |
| 19 | 8.18 | 9.50 |
| 23 | 5.08 | 6.07 |
| 29 | 3.43 | 2.95 |
| 30 | 2.67 | 3.10 |
| 1978 | | |
| Jan. | | |
| 3 | 1.96 | 1.83 |
| 4 | 1.57 | 1.40 |
| 5 | 4.88 | 8.74 |
| 5 | 3.35 | 3.28 |
| 6 | 3.61 | 5.77 |
| 9 | 3.76 | 3.07 |
| 9 | 1.96 | 2.95 |
| 10 | 0.46 | 0.41 |
| 11 | 0.25 | 2.13 |
| 13 | 0.33 | 0.08 |
| 16 | 14.53 | 20.04 |
| 16 | 0.58 | 1.96 |
| 17 | 4.57 | 4.75 |
| 18 | 0.08 | 0.08 |
| Feb. | | |
| 2 | 1.24 | 0.81 |
| 3 | 0.15 | 1.40 |
| 6 | 4.62 | 5.13 |
| 7 | 4.45 | 5.92 |
| 8 | 2.24 | 1.04 |
| 9 | 4.80 | 3.07 |
| 10 | 0.08 | 0.33 |
| 13 | 2.87 | 3.51 |
| 15 | 0.66 | 0.61 |
| Mar. | | |
| 2 | 2.92 | 3.35 |
| 3 | 2.92 | 1.30 |
| 6 | 10.11 | 11.25 |
| 9 | 0.18 | 1.88 |
| 10 | 0.05 | 0.13 |
| Sum | 109.28 | 124.36 |
| Mean | 3.2141 | 3.6577 |
| Standard error | | 1.2583 |
| r square | | 0.8548 |
| Regression coefficients | | |
| $a_0$ | | 0.4648 |
| $a_1$ | | 0.7517 |

precipitation gage catch from snow gage change in snowpack water equivalent (*table 2*) using $P_w = a_0 + a_1 P_{sg}$, in which $a_0$ (0.4648) and $a_1$ (0.7517) are regression coefficients and $P_w$ and $P_{sg}$ are weighing bucket precipitation and snow gage change in water equivalent, respectively (*fig. 5*).[8]

After a storm, the change in total snowpack water equivalent should suggest the amount of precipitation that fell, if no melt occurred during the storm. Melt is defined as an easily discernible water loss between each density profile, as measured by the snow gage. If a large amount of new snow is deposited upon a mature (ripe) snowpack, a small water loss could occur as a result of a change in water-holding capacity (capillarity) of the snowpack, caused by compaction and changes in the internal structure of the snow.[9] Under these conditions, precipitation can be estimated only with the water equivalent of the new-fallen snow. During periods of heavy melt, the profiling snow gage cannot be used to measure precipitation because changes in snowpack water equivalent will not indicate actual precipitation. From *figure 5*, snow gage change in water equivalent between measurements can be determined from weighing bucket gage catch for that same period; that amount may be more indicative of actual precipitation. The methodology described here should be adaptable to snow pressure pillow data to obtain a reasonable estimation of precipitation.

Wind did not seem to cause either over-measure or under-measure of new-fallen snow by the snow gage relative to precipitation catch by the weighing bucket gage (*table 3, fig. 6*). Comparison of precipitation amounts between each density profile, as measured by the weighing bucket gage, with the change in snowpack water equivalent, as measured by the profiling snow gage, indicated no significant trends due to average 24 hour windspeed and directional changes. For instance, at 5 mi/h (8.1 km/h) average windspeed, the weighing bucket precipitation gage recorded more precipitation than the snow gage during one storm and vice versa during another storm (*fig. 6*). Wind direction was the same for both storms. This variability was present

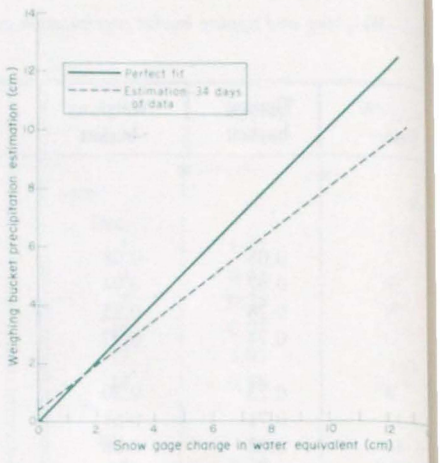


**Figure 5**—Catch by the weighing bucket precipitation gage was estimated by linear regression analysis of the change in snowpack water equivalent by the snow gage.

regardless of windspeed and direction, no trends were evident. The only observed wind effects were on the snow surface. At times, very high winds tended to scour the snow surface and cause a redistribution of snow. The scouring, in association with wind compaction, could have caused some of the catch discrepancy between the two gages.

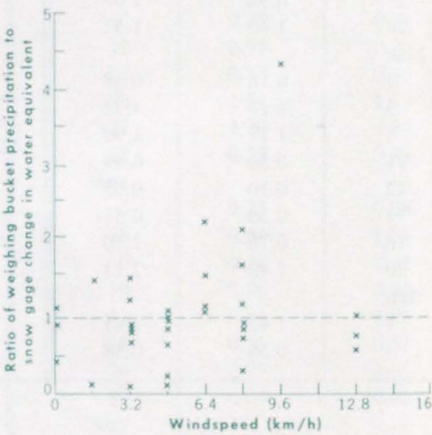


**Figure 6**—Ratio of weighing bucket precipitation to snow gage change in water equivalent in relation to windspeed.

Table 3—*Weighing bucket precipitation and snow gage change in water equivalent, from one snow gage measurement to the next, in relation to windspeed and direction*

| Weighing bucket precipitation (cm) | Snow gage change in water equivalent | Ratio | Wind-speed | Direction |
|---|---|---|---|---|
| | *cm* | | *km/h* | |
| 1.70 | 1.14 | 1.49 | 1.6 | S |
| 9.04 | 5.38 | 1.68 | 8.1 | SW |
| 8.18 | 9.50 | 0.86 | 3.3 | NW |
| 5.08 | 6.07 | 0.84 | 4.9 | SSW |
| 3.43 | 2.95 | 1.16 | 8.1 | S |
| 2.67 | 3.10 | 0.86 | 8.1 | SSW |
| 1.96 | 1.83 | 1.07 | 4.9 | SW |
| 1.57 | 1.40 | 1.13 | 6.5 | SW |
| 4.88 | 8.74 | 0.56 | 13.0 | SW |
| 3.35 | 3.28 | 1.02 | 13.0 | SW |
| 3.61 | 5.77 | 0.63 | 4.9 | SW |
| 3.76 | 3.07 | 1.22 | 3.3 | S |
| 1.96 | 2.95 | 0.66 | 3.3 | S |
| 0.46 | 0.41 | 1.13 | Calm | |
| 0.25 | 2.13 | 0.12 | 4.9 | S |
| 0.33 | 0.08 | 4.33 | 9.8 | S |
| 14.53 | 20.04 | 0.72 | 8.1 | S |
| 0.58 | 1.96 | 0.30 | 8.1 | S |
| 4.57 | 4.75 | 0.96 | 4.9 | SSW |
| 0.08 | 0.08 | 1.00 | 4.9 | S |
| 1.24 | 0.81 | 1.53 | 3.3 | S |
| 0.15 | 1.40 | 0.11 | 1.6 | S |
| 4.62 | 5.13 | 0.90 | 8.1 | S |
| 4.45 | 5.92 | 0.75 | 13.0 | S |
| 2.24 | 1.04 | 2.15 | 8.1 | S |
| 4.80 | 3.07 | 1.56 | 6.5 | S |
| 0.08 | 0.33 | 0.23 | 4.9 | N |
| 2.87 | 3.51 | 0.82 | 3.3 | S |
| 0.66 | 0.61 | 1.08 | 6.5 | S |
| 2.92 | 3.35 | 0.87 | 3.3 | S |
| 2.92 | 1.30 | 2.25 | 6.5 | S |
| 10.11 | 11.25 | 0.90 | Calm | |
| 0.18 | 1.88 | 0.09 | 3.3 | E |
| 0.05 | 0.13 | 0.40 | Calm | |

## NOTES


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